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Performance Analysis of Various Filters for De-Speckling of Thyroid Ultrasound Images

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Abstract *Thyroid ultrasonography is the most common and extremely useful, safe, and cost effective way to image the thyroid gland and its pathology. However, an inherent characteristic of Ultrasound (US) imaging is the presence of multiplicative speckle noise. Speckle noise reduces the ability of an observer to distinguish fine details, make diagnosis more difficult. It limits the effective implementation of image analysis steps such as edge detection, segmentation and classification. The main objective of this study is to compare the performance of various spatial and frequency domain filters so as to identify efficient and optimum filter for de-speckling Thyroid US images. The performance of these filters is evaluated using the image quality assessment parameters Signal to Noise Ratio (SNR), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index (SSIM), Mean Square Error (MSE) and Root Mean Square Error (RMSE) for different speckle variance. Experimental work revealed that kuan filter resulted in higher PSNR, SNR, SSIM and least MSE, RMSE values compared to other filters.*

Keywords *De-speckling, Filters, MSE, PSNR, RMSE, SNR, Speckle noise, SSIM, Thyroid Ultrasound*

I. INTRODUCTION

The introduction of US imaging has revolutionized the diagnostics of thyroid pathologies. Nowadays, thyroid US examination has become an essential part of routine thyroid gland evaluation [1]. Ultrasonography produces the images in real time and is the most widely preferred imaging technique because of its noninvasive, painless, low cost, harmless and portable properties. The quality of information from the ultrasound device has been increased in recent years due to the advancement of technology [2]. It does not expose patients to radioactive isotopes or Roentgen radiation, quick and comfortable for patients, and so can be repeated without any harm and be performed even in children or pregnant women. However, the main disadvantage of medical ultrasonography is the poor quality of images, which are affected by multiplicative speckle noise [3]. Speckle noise affects all coherent imaging modalities and makes it difficult to perform further processing. It is caused by the constructive and destructive interference of back scattered coherent waves from the transducer at different phases [4]. Speckle is a random multiplicative noise and it affects the extraction and interpretation of fine details in the image there by reducing the diagnostic value of US imaging modality. Hence speckle reduction techniques have to be applied to denoise images as well as to enhance the visual quality of images [5]. However, the aim of denoising procedure is to remove the speckle without destroying the clinically significant features. Generally, these denoising filters can be classified based on their domain of denoising - spatial or frequency domain [6].

This paper is organized as follows. Section II describes related research work carried out to de-speckle US images. The de-speckling filters used in this study is shown diagrammatically in section III. Results of experiments are detailed in Section IV, followed by discussion and conclusions in section V and VI respectively.

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II. SPECKLE REDUCTION FOR MEDICAL US IMAGES –RELATED WORK

Many researchers engaged in image processing have proposed various filters for speckle noise removal while holding finer details and edges from US images. Gopinathan S et al., [7] applied Lee, Frost, Kuan, Wiener, Median, Speckle Reducing Anistrophic Diffusion (SRAD) filters to denoise photographic, US, SAR, PET, CT and MRI images. The statistical measures SNR, PSNR, SSIM, MSE and RMSE were used for comparing the performance of filters for removal of speckle noise. Out of six filters used Lee, Kaun and SRAD filters gave best results for Photographic and CT images. SRAD and Median filters gave best results for US, SAR and PET images and Weiner Filter gave best results for MR images. Savaliya Nirali H et al., [8] applied Mean, Median, Lee, Frost, Kuan, SRAD and Perona-Malik Anisotropic Diffusion filters to denoise US images containing renal stone. The statistical measures SNR, PSNR, MSE, RMSE, Average Difference (AD), and Speckle Index (SI) were used for comparing the performance of filters. Spatial filters removed speckle noise but some details were lost. PDE based SRAD and PMAD filters gave better de-noising and with edge prevention but required more iteration to reach convergence. Ines Njeh et al., [9] proposed a novel SMU (SRAD Median Unsharp) algorithm for speckle removal in US breast images. SMU algorithm gave best results when compared to SRAD, Frost, Kuan, wiener and Wavelet threshold filters in terms of mean, MSE, PSNR, SSIM and Edge Preserving Index (EPI). J Nithya et al., [10] used a multiscale representation, curvelet transform (CT) for speckle denoising of fetal US images (FUS). The performance of CT is compared with SRAD, Modified SRAD and SUSAN filters in terms of MSE, PSNR, Structural Content (SC), and Normalized Absolute Error (NAE) for different variances.

Low SC, NAE, MSE, high PSNR values and visual quality indicated that CT performed efficient de-speckling of FUS images involving curved structures.

B.Kirthika et al., [11] performed a comparative analysis of Median, Wavelet, Homomorphic, Butterworth, Ideal, Homomorphic butterworth and Homomorphic wavelet filters to denoise US B-mode images. Homomorphic butterworth filter with less MSE, higher SNR and PSNR values removed speckle noise effectively when compared to other filters. Ruchita Gupta et al., [12] carried out an experiment using wiener filter to remove mixed noise, which is a combination of speckle and gaussian noise from Intravascular US images. PSNR and MSE values are computed for degraded and filtered images with different speckle noise and constant Gaussian noise. The experiment is repeated keeping speckle constant and varying gaussian noise. Apart from PSNR & MSE measures, visual quality of the denoised images is used for performance evaluation. The wiener filter is effective in removing speckle and gaussian noise, preserving edges and gave better PSNR & MSE values for enhanced image in comparison to degraded image. R. Vanithamani et al., [13] applied Mean, Lee, Kuan, Frost, Median, Homomorphic, SRAD and Non Linear Coherent Diffusin (NCD) filters to despeckle US images of liver. The performance is compared based on PSNR, SNR, RMSE, SSIM, Image Quality Index and Edge Preservation Factor. Results indicated performance of SRAD filter is better in terms of speckle suppression and detail preservation.

III. DE-SPECKLING FILTERS USED IN THIS STUDY

Filters provide an aid to visual interpretation of images [14]. The filters used in the present study for de-speckling of TUS images include both spatial and frequency domain filters as depicted in Fig. 1 [15].

IV. EXPERIMENTAL RESULTS

Procedure adopted for the experimental work is briefed below.

Step 1: Repeat step 2 to step 6 with different speckle variance (0.08, 0.09, 0.1, 0.2, 0.3, 0.4 and 0.5).

Step 2: Read original TUS image which is stored in jpg format.

Step 3: Add speckle variance to original TUS image

Step 4: Noisy TUS image is filtered using different filters.

Step 5: Compute SNR, PSNR, MSE, RMSE and SSIM for noisy and filtered image.

Step 6: Compare the Filtered image with noisy image using statistical parameters.

Step 7: display the best filter for the corresponding input TUS image.

US images of normal and abnormal thyroid gland (goiter, benign and malignant nodules) were collected from radiology department of Jindal hospital, Bangalore. These images were captured using a high resolution ACUSON X300 Ultrasound system and stored in Digital Imaging and Communications in Medicine (DICOM) format. US images are resized to 512*512 and converted to jpg format. Filters were implemented using Image processing toolbox under Matlab R2014a software [16]. The images with added speckle noise are depicted in Fig. 2. De-speckled images using all the fourteen filters used for experimental work is shown in Fig. 3. Table I shows PSNR, SNR, MSE, RMSE and SSIM values for speckle added noisy image. The performance comparison of various filters for speckle variance 0.08, 0.09, 0.1, 0.2, 0.3,0.4 and 0.5 are given in Table II, Table III, Table IV, Table V, Table VI, Table VII and Table VIII respectively. Fig.4, Fig 5, Fig 6, Fig 7 and Fig 8 shows graph of average PSNR, SNR, MSE, RMSE and SSIM values of all filters respectively.

V. DISCUSSION

Filters re-evaluate the value of every pixel in an image. This paper provides a study of different spatial and frequency domain filters, their evaluation and then describes a comparative analysis of the discussed filters using quantitative measures like PSNR, SNR, MSE, RMSE and SSIM [17]. To quantify the performance of the filters, known speckle noise is added to input images. Noisy images are de-noised using different filters.

From the experimental results it can be concluded that Kuan filter is optimal compared to all other spatial filters. Kaun filter resulted in the maximum PSNR value of 48.6057, SNR value of 33.9227 and SSIM value of 0.9938 compared to PSNR of 25.7584, SNR of 11.2748, and SSIM of 0.5716 of noisy image for speckle variance 0.08. Also, Kuan filter resulted in minimum MSE value of 0.8964 and RMSE value of 0.9468 against MSE value of 172.68 and RMSE value of 13.1408 of a noisy image for speckle variance of 0.08. Mean and weighted mean filters performed well compared to wiener, median, max and min spatial domain filters. Among the frequency domain filters GLPF performed well compared to ILPF, BLPF and high boost filters. GLPF resulted in the maximum PSNR value of 34.5734, SNR value of 19.7607 and SSIM value of 0.8941 against PSNR value of 25.7584, SNR of 11.2748 and SSIM of 0.5716 for speckle variance of 0.08. Also, GLPF resulted in minimum MSE value of 22.6852 and RMSE value of 4.7629 against MSE value of 172.6806 and RMSE value of 13.1408 of a noisy image for speckle variance of 0.08.The tabulated values show that max, min and high boost filters did not perform well for different values of variance.

VI. CONCLUSION

Medical imaging is a strong supporting element in medical decision-making. Medical images are complex and unfortunately are often affected by noise, which can decrease the quality of these images. To denoise these images, it is necessary to apply various filtering techniques. Since selection of the right denoising filter plays a major role, it is important to experiment and compare the various filters with differing variance. In this paper, denoising is carried out using fourteen filters for TUS images. The performance of these filters is evaluated using the image quality assessment parameters SNR, PSNR, SSIM, MSE and RMSE. Kuan filter is effective in removing speckle noise, preserving important details and edges. It enhances the visual quality of TUS images by achieving maximum SNR, PSNR, SSIM and minimum MSE, RMSE values.

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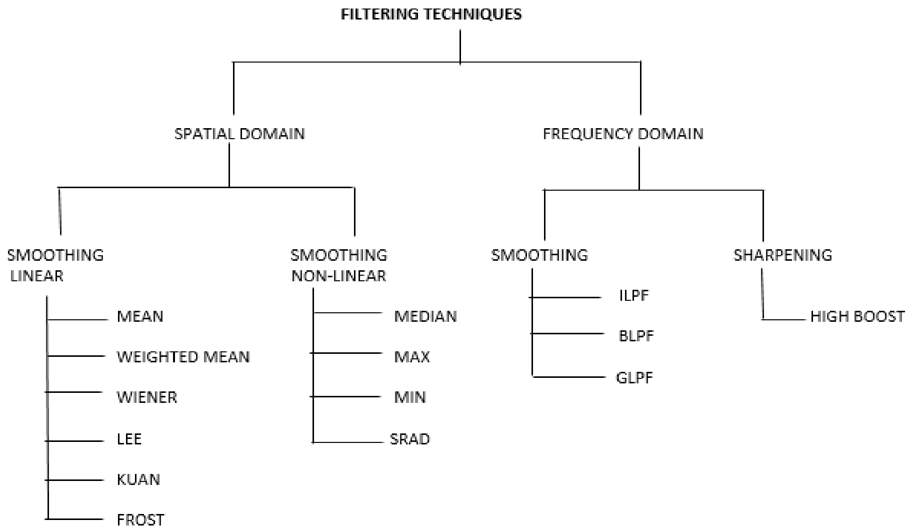


Fig.1 Categorization of filters applied to Thyroid Ultrasound Images

Table I: SNR, PSNR, MSE, RMSE and SSIM for a Noisy TUS Image for different variance

Noise Variance	PSNR	SNR	MSE	RMSE	SSIM
0.08	25.7584	11.2748	172.6806	13.1408	0.5716
0.09	25.2827	10.8484	192.6670	13.8805	0.5505
0.1	24.8091	10.4078	214.8666	14.6583	0.5300
0.2	21.7958	7.7764	430.0289	20.7371	0.3986
0.3	20.0720	6.3766	639.5585	25.2895	0.3315
0.4	18.8533	5.4948	846.7481	29.0989	0.2898
0.5	18.0409	4.9745	1.0209e+03	31.9517	0.2638

Table II: Performance Comparison of various filters for speckle variance 0.08

Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	33.6941	19.1728	27.7763	5.2703	0.8748
Weighted Mean	33.5909	18.7782	28.4439	5.3333	0.8712
Wiener	30.1497	15.3370	62.8225	7.9261	0.8226
Median	31.1169	16.3042	50.2792	7.0908	0.7953
Max	21.1870	6.3744	494.7385	6.3744	0.7430
Min	22.0550	7.2423	405.1182	20.1275	0.6782
ILPF	33.2062	18.3935	31.0788	5.5748	0.8521
BLPF	34.5001	19.6873	23.0713	4.8033	0.8935
GLPF	34.5734	19.7607	22.6852	4.7629	0.8941
High boost	17.4628	7.6665	1.1076e+03	33.2805	0.6877
SRAD	33.8624	19.4572	26.7206	5.1692	0.9476
Lee	32.1704	17.4327	39.4496	6.2809	0.8289
Kuan	48.6057	33.9227	0.8964	0.9468	0.9938
Frost	27.3899	12.7500	118.6018	10.8904	0.6424

Table III: Performance Comparison of various filters for speckle variance 0.09

Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	33.2986	18.7774	30.4242	5.5158	0.8651
Weighted Mean	33.1756	18.3650	31.2979	5.5945	0.8605
Wiener	29.6433	14.8306	70.5909	8.4018	0.8085
Median	30.7022	15.8895	55.3168	7.4375	0.7822
Max	20.8026	5.9899	540.5299	23.2492	0.7300
Min	21.6409	6.8281	445.6624	21.1107	0.6578
ILPF	32.8451	18.0324	33.7030	5.8115	0.8448
BLPF	34.2805	19.4677	24.2681	4.9263	0.8896
GLPF	34.3478	19.4050	24.6212	4.9620	0.8874
High boost	17.5519	7.5930	1.1426e+03	28.5400	0.7899
SRAD	33.5404	19.1846	28.6630	5.3538	0.9480
Lee	31.7515	16.9834	43.4441	6.6246	0.8173
Kuan	48.3616	33.8453	0.9483	0.9738	0.9937
Frost	26.9633	12.3588	129.7373	11.3902	0.6272

Table IV: Performance Comparison of various filters for speckle variance 0.1

Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	33.6941	18.4516	32.7944	5.7266	0.8552
Weighted Mean	32.7281	17.9154	34.6950	5.8902	0.8489
Wiener	29.2170	14.4043	77.8704	8.8245	0.7974
Median	30.2270	15.4143	61.7139	7.8558	0.7644
Max	20.4070	5.5943	592.0769	24.3326	0.7191
Min	21.2690	6.4563	485.4934	22.0339	0.6338
ILPF	32.6929	17.8802	34.9774	5.9142	0.8404
BLPF	33.0341	19.2213	25.6846	5.0608	0.8843
GLPF	34.2711	19.9585	24.0595	4.9593	0.8809
Highboost	17.4483	7.5339	1.1707e+03	34.2160	0.6832
SRAD	33.2500	18.9029	30.7661	5.5468	0.9482
Lee	31.3405	16.6260	47.7565	6.9106	0.8070
Kuan	48.2939	33.6765	0.9631	0.9801	0.9935
Frost	26.5977	11.9670	142.3350	11.9304	0.6157

Table V: Performance Comparison of various filters for speckle variance 0.2

Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	30.4445	15.9243	58.6582	7.6606	0.7550
Weighted Mean	29.9616	15.1487	65.6025	8.0995	0.7617
Wiener	26.2184	11.4057	155.3234	12.4629	0.7043
Median	27.3515	12.5388	119.6550	10.9387	0.6502
Max	17.8242	3.0116	1.0731e+03	52.7586	0.6258
Min	18.5917	3.7790	899.3201	29.9887	0.4343
ILPF	31.0330	16.2212	51.2470	7.1589	0.7956
BLPF	32.1914	17.3786	39.2595	6.2657	0.8430
GLPF	31.7526	16.9399	43.4332	6.5903	0.8249
Highboost	16.4232	7.1276	1.4817e+03	38.4929	0.6760
SRAD	31.6909	17.6155	44.0550	6.6374	0.9566
Lee	28.6541	14.0710	88.6492	9.4154	0.7320
Kuan	47.1526	32.5310	1.2442	1.1153	0.9918
Frost	24.0297	9.4182	257.1075	16.0346	0.5394

Table VI: Performance Comparison of various filters for speckle variance 0.3

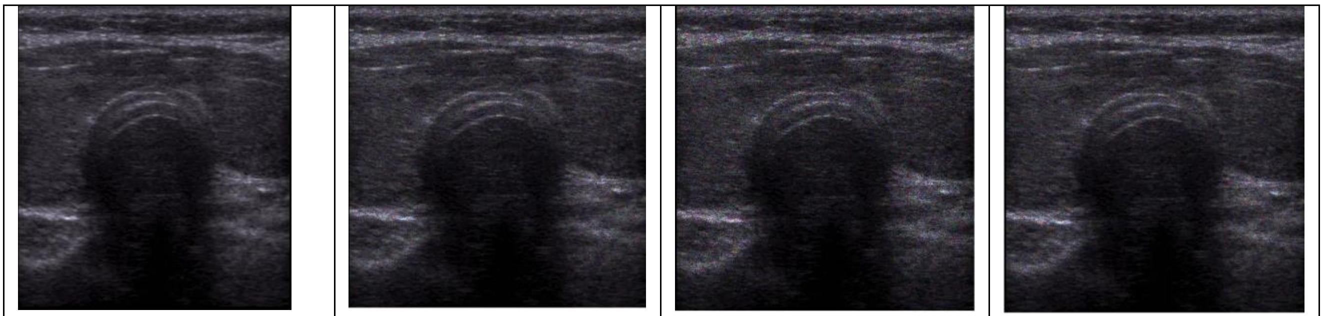
Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	28.9195	14.3983	83.3928	9.1320	0.7147
Weighted Mean	28.3267	13.5140	95.5892	9.7770	0.6993
Wiener	24.4283	9.6153	234.5571	15.3153	0.6401
Median	25.6942	10.8815	175.2529	13.2383	0.5775
Max	16.2709	1.4582	1.5346e+03	39.1738	0.5609
Min	16.9172	2.1045	1.3224e+03	36.3645	0.2722
ILPF	29.8400	15.0274	67.4646	8.2137	0.7580
BLPF	30.9565	16.1437	52.1709	7.2229	0.8084
GLPF	30.3782	15.5665	59.6015	7.7202	0.7795
High boost	15.8316	6.9760	1.6979e+03	41.2062	0.6794
SRAD	30.2672	16.5232	61.1447	7.8195	0.9597
Lee	26.9753	12.4991	130.4829	11.4229	0.6844
Kuan	46.2254	31.6336	1.5508	1.2453	0.9905
Frost	22.5355	7.9559	362.6865	19.0443	0.5077

Table VII: Performance Comparison of various filters for speckle variance 0.4

Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	27.7804	13.2591	108.4038	10.4117	0.6654
Weighted Mean	27.1927	12.3800	124.1110	11.1405	0.6489
Wiener	23.2769	8.4642	305.7654	17.4862	0.5974
Median	24.4265	9.6138	234.6554	15.3185	0.5226
Max	15.1327	0.3201	1.9945e+03	44.6484	0.5111
Min	15.9024	1.0897	1.6705e+03	40.8715	0.1661
ILPF	28.9840	14.1713	82.1633	9.0644	0.7273
BLPF	30.0893	15.2765	63.7023	7.9844	0.7801
GLPF	31.4541	15.6414	73.7351	8.5869	0.7456
High boost	15.4059	6.9098	1.8768e+03	43.2760	0.6822
SRAD	29.4347	15.9580	74.0641	8.6060	0.9628
Lee	25.8529	11.4950	168.9631	12.9986	0.6535
Kuan	45.5092	30.9381	1.8288	1.3523	0.9893
Frost	21.5163	6.9699	458.6151	21.4153	0.4956

Table VIII: Performance Comparison of various filters for speckle variance 0.5

Filter	PSNR	SNR	MSE	RMSE	SSIM
Mean	27.0748	12.9450	127.6420	11.2979	0.6426
Weighted Mean	26.4310	11.6391	147.9058	12.1617	0.6841
Wiener	22.4692	8.2361	368.2668	19.1903	0.5837
Median	23.4773	8.6477	291.9756	17.0873	0.4988
Max	14.2721	0.1432	1.0233e+03	31.9009	0.5027
Min	15.4980	1.0231	1.8335e+03	42.8192	0.1568
ILPF	28.3998	14.0879	91.0977	9.5445	0.7198
BLPF	29.4758	14.8231	73.3675	8.5655	0.7731
GLPF	28.6307	13.9802	89.1275	9.4407	0.7421
High boost	14.8422	6.2190	1.9358e+03	43.9981	0.6219
SRAD	28.9054	15.2077	83.6637	9.1468	0.9213
Lee	25.0962	11.2140	201.1207	14.1817	0.6231
Kuan	44.9729	29.8690	2.0691	1.4384	0.9811
Frost	20.4987	6.0521	538.90	23.2142	0.4832



(a) (b) (c) (d)

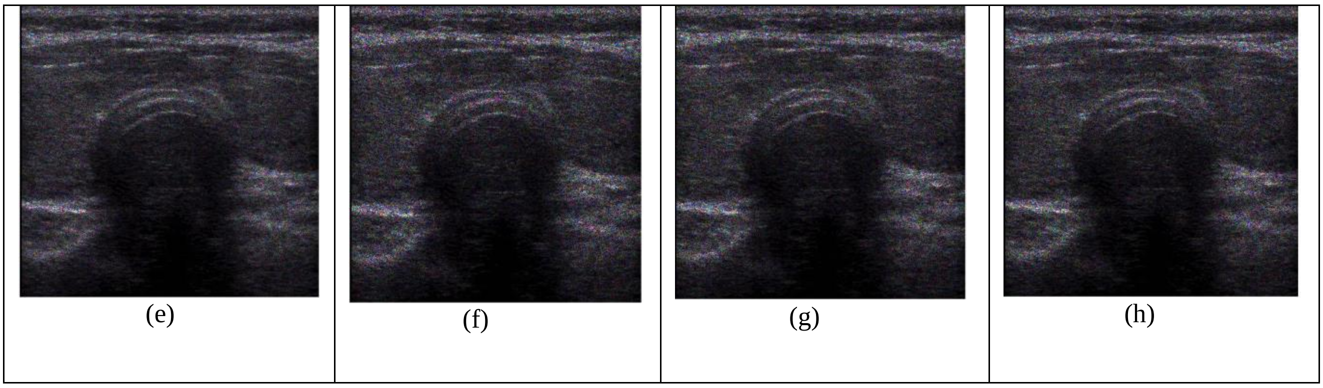


Fig. 2 (a) Original TUS image (b) Noisy image with variance 0.08 (c) Noisy image with variance 0.09 (d) Noisy image with variance 0.1 (e) Noisy image with variance 0.2 (f) Noisy image with variance 0.3 (g) Noisy image with variance 0.4 (h) Noisy image with variance 0.5

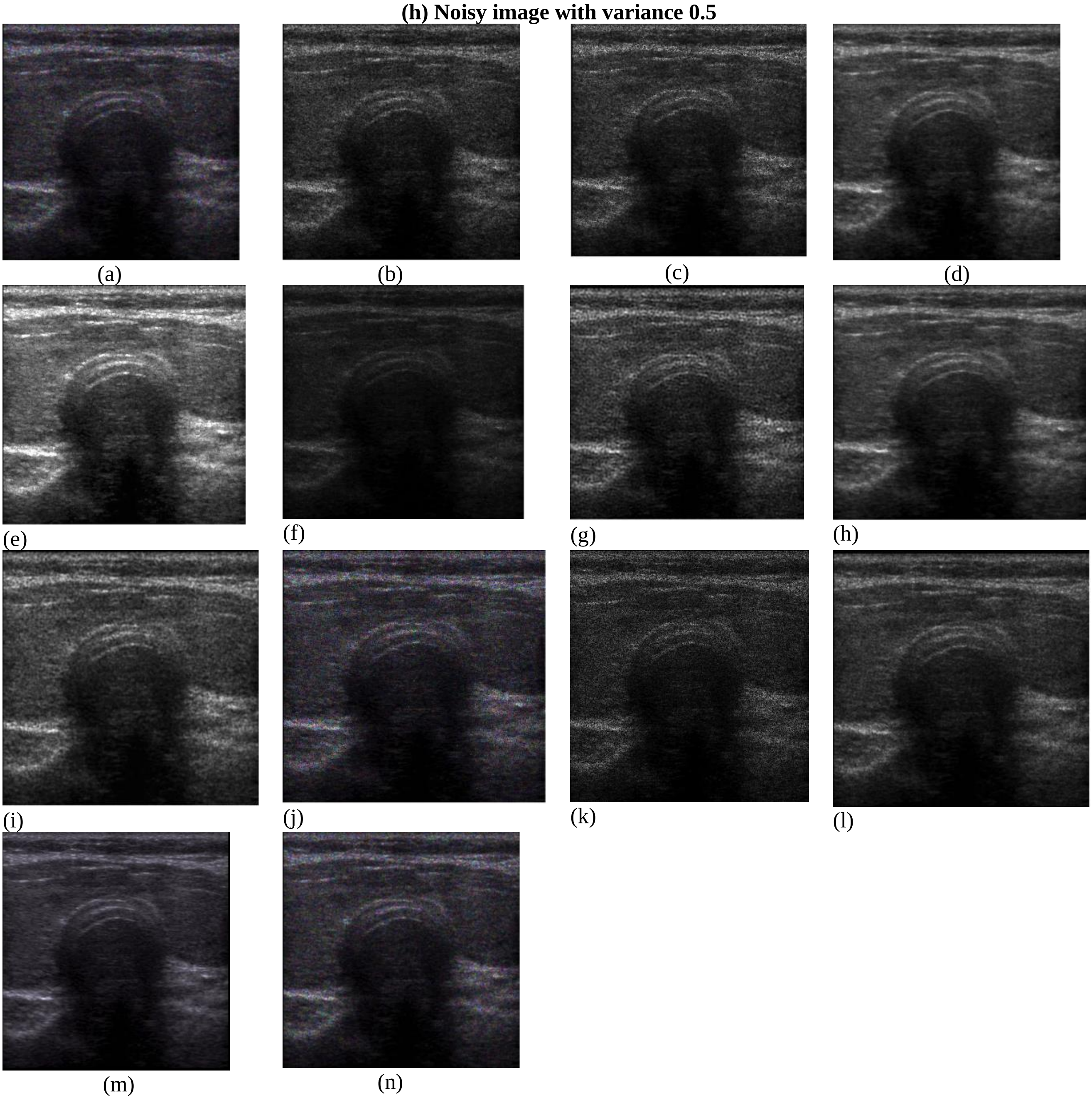


Fig. 3 Filtered TUS images using (a) mean filter (b) weighted mean filter (c) wiener filter (d) median filter (e) max filter (f) min filter (g) ILPF (h) BLPF (i) GLPF (j) SRAD (k)High boost (l) Lee (m) Kuan & (n) Frost filters

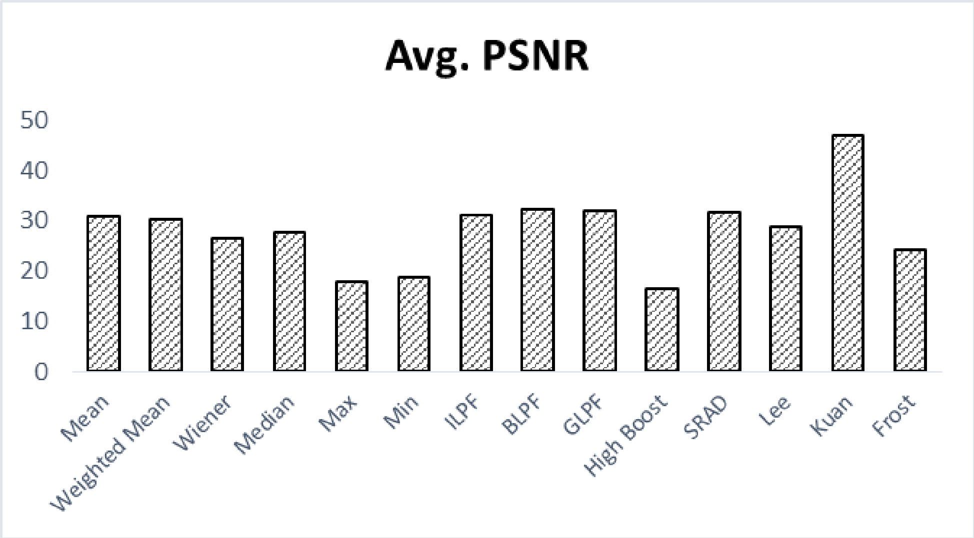


Fig.4 Average PSNR values of different filters

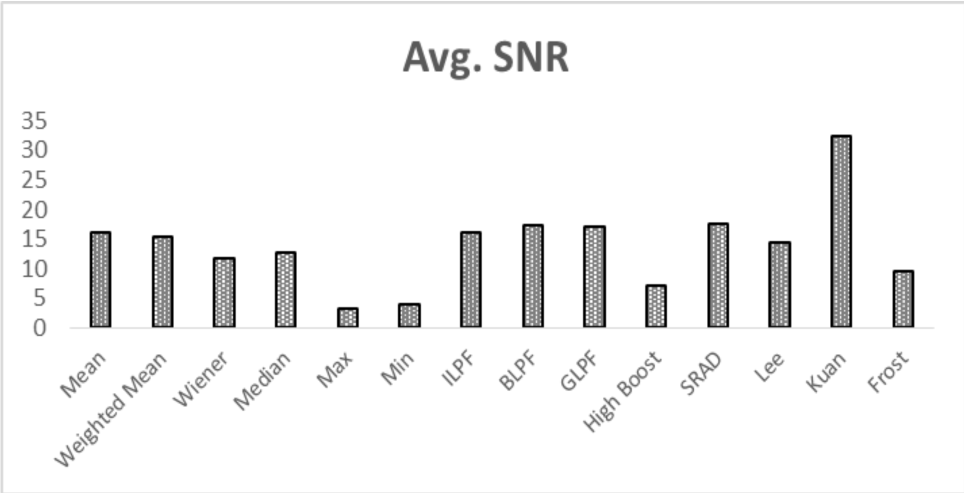


Fig.5 Average SNR values of different filters

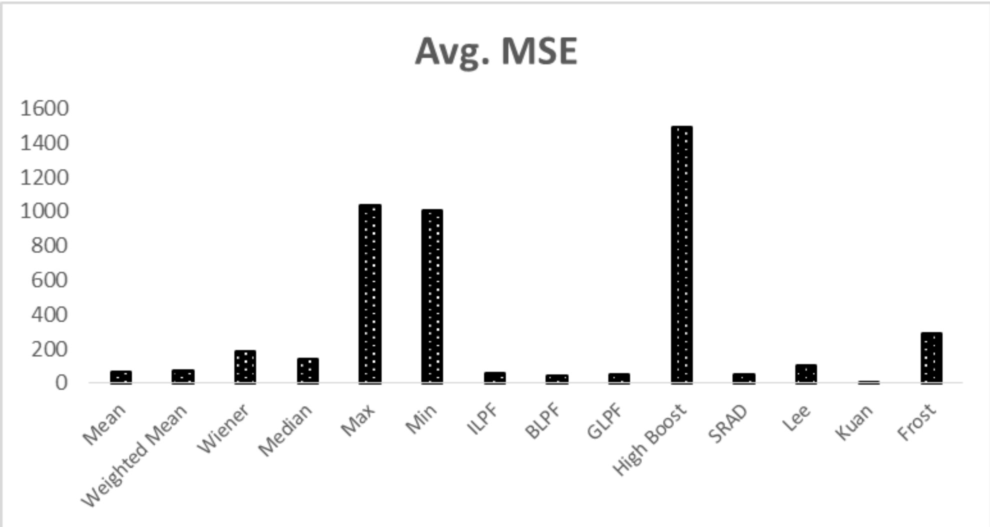


Fig.6 Average MSE values of different filters

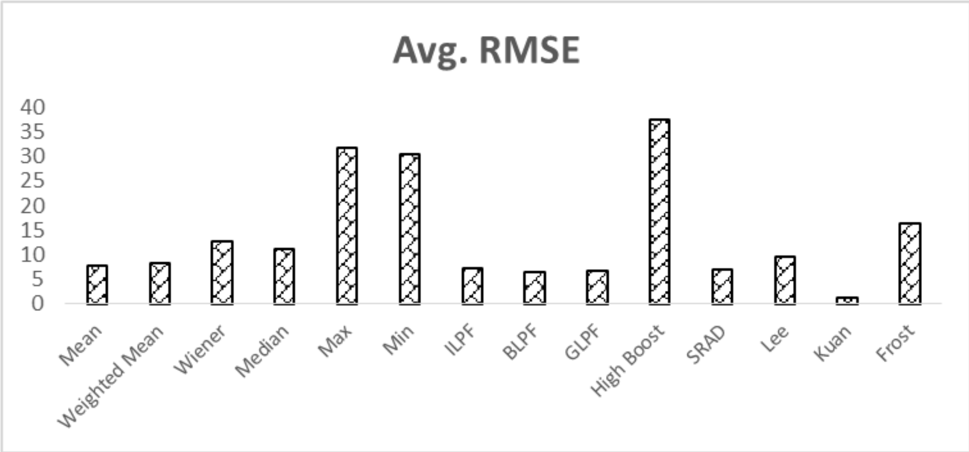


Fig. 7 Average RMSE values of different filters

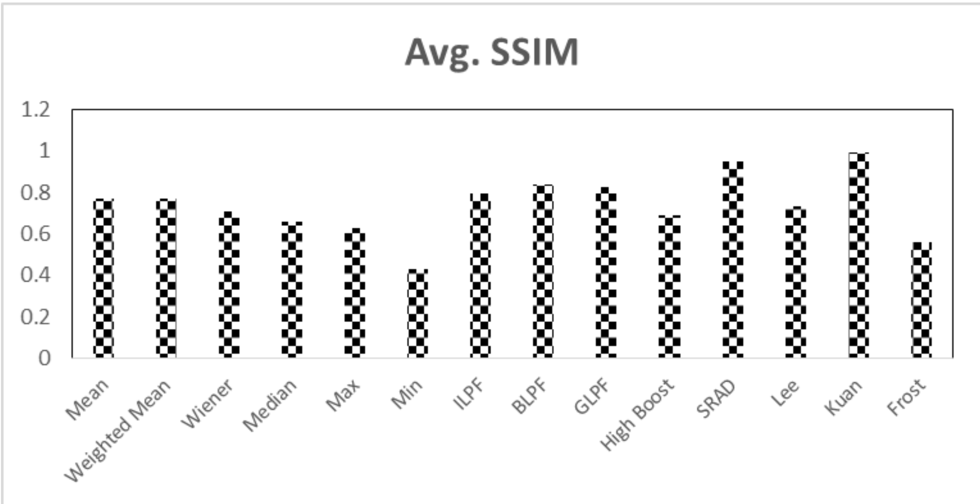


Fig. 8 Average SSIM values of different filters

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